A COMPARISON OF AM AND VARIOUS SSB MODELS ON 2182 KHZ

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NAVAL POSTGRADUATE SCHOOL

Monterey, California

THESIS

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AND VARIOUS SSB MODES
ON 2182 KHZ

by

Kenneth Richard Mass

September 1975

Thesis Advisor: C.F. Klamm

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) A Comparison of AM and Various SSB Modes on 2182 kHz		5. TYPE OF REPORT & PERIOD COVERED Master's Thesis; September 1975
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Kenneth Richard Mass		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		12. REPORT DATE September 1975
		13. NUMBER OF PAGES 40
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

2182 kHz
Single sideband
SSB Modes

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

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A Comparison of AM
and Various SSB Modes
on 2182 kHz

by

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Lieutenant, United States Coast Guard
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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN ELECTRICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL

September 1975

ABSTRACT

The Federal Communications Commission is requiring a conversion to single sideband on the 2 MHz band. However, on 2182 kHz, because of international agreement; only the A3H mode is authorized after 1 January, 1977. Many users of this mode have reported a drastic reduction in range of transmission, using authorized power levels. This thesis is a comparison of power requirements for AM and single sideband, and a discussion of the A3H problem.

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I. INTRODUCTION

The study of communications is probably as old as man. Anytime two people come together, they attempt to communicate. And the history of communications may have begun with someone stranded on a floating log, calling to the shore for help. Since that time, man has progressed through other sound communications, such as bells, whistles, cannon fire, etc.; and visual communications, such as fires, lights, and flags. But the development of radio marked the beginning of instantaneous long range communications.

Marconi and others, around the turn of the century, were able to transmit electrical energy without the use of wires;[1] first for a few miles, then many miles, then hundreds of miles. Soon, the United States Navy was looking at this invention for possible use aboard ships. Maritime radio communications had begun.

The first radio transmissions were telegraphic in nature. Codes such as the Morse code were used, and operators sent dots, dashes, and spaces by turning on and off their transmitters.

In the early 1900's people began working on radio-telephone experiments. In 1907,[2] DeForrest demonstrated

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[1]Howard, L.S., History of Communications - Electronics in the United States Navy, U.S. Government Printing Office, Washington, D.C. (1963).

[2]Ibid.

that voices could be transmitted by varying the amplitude of a radio signal — amplitude modulation. However, it was not until 1917 that the first completely successful voice modulated equipment was introduced.

Two years earlier, in 1915, John Carson had invented single sideband. Single sideband later came in to use over telephone landlines because of its spectrum saving characteristics. In the late twenties, it was used for overseas radiotelephone. Since World War II, however, single sideband has come in to general use by radio amateurs and others.

Radio interference is as old as radio. The first conference on ways to reduce interference was held in 1907,[3] and many others have been held since then. This is important because frequently men become stranded in ships and boats. And like the early man on the log, they call for help.

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[3]Ibid.

II. STANDARD AM

Standard AM, or more properly, amplitude modulation double sideband with carrier; was the first modulation scheme used for voice communications. It is produced by impressing a baseband (audio) signal on a higher frequency carrier signal. The result is a higher (than audio) frequency signal whose amplitude varies with the voice signal. Figure 1 shows a block diagram of an AM transmitter.

Detection of AM-DSB/WC is relatively simple. The incoming radio frequency signal can be amplified first or mixed directly with a local oscillator signal. Usually, this is to heterodyne the signal to a fixed intermediate frequency signal. This IF signal is amplified before going to an envelope detector. In its simplest form, an envelope detector is a rectifier followed by a low pass filter. The output of the detector is the audio frequency signal, which is amplified and sent to the speaker or headphones. Figure 2 is a block diagram of a modern superheterodyne AM receiver.

In the time domain, a standard AM signal is described by the following equation:

$$e_{AM}(t) = A[1 + m_a\, g(t)] \cos 2\pi f_c t$$

where $\underline{A}$ is the amplitude of the unmodulated carrier, $\underline{m_a}$ is the modulation index (ranging from 0 to 1), g(t) is the modulating signal, and f_c is the carrier frequency.

In the special case of modulation by a single sinusoidal signal of frequency f_m, the time domain function may be written:

$$e_{AM}(t) = A[1 + m_a \sin 2\pi f_m t] \cos 2\pi f_c t$$

Figure 3(a) shows this time domain waveform. For purposes of clarity, the carrier is shown much lower than it would normally be.

The frequency domain is of more interest. Figure 3(b) shows the power spectrum for the sinusoidal modulation case. We see a pair of symmetrical sidebands on either side of the carrier frequency. For the case of voice modulation, the sidebands would appear as a continuous spectrum; extending out on each side to the bandwidth of the audio signal.

Of importance is the power in each of the sidebands and the carrier. All voltages will be assumed to be across a one ohm resistance. The average carrier power is

$$P_{CAR} = \frac{A^2}{2}$$

and each sideband has an average power of

$$P_{SB} = \frac{m_a^2 A^2}{8}$$

The total sideband average is, therefore,

$$P_{TOT} = P_{USB} + P_{LSB} = \frac{m_a^{\,2}\, A^2}{4}$$

At 100% modulation ($m_a = 1$), the total power in the sidebands is equal to one-half that in the carrier.

If white noise is assumed and total noise power is N, the input signal-to-noise ratio is

$$(S/N)_{IN} = \frac{m_a^{\,2}\, A^2}{4N}$$

However, in cases of large carrier-to-noise ratios, the sidebands add coherently. This leads to a doubling of the signal-to-noise ratio at the output of the detector, giving us

$$(S/N)_{OUT} = \frac{m_a^{\,2}\, A^2}{2N}$$

This says that under favorable conditions, an envelope detector works as well as a coherent detector. This is valid for decreasing carrier-to-noise ratios until noise threshold effects become important.

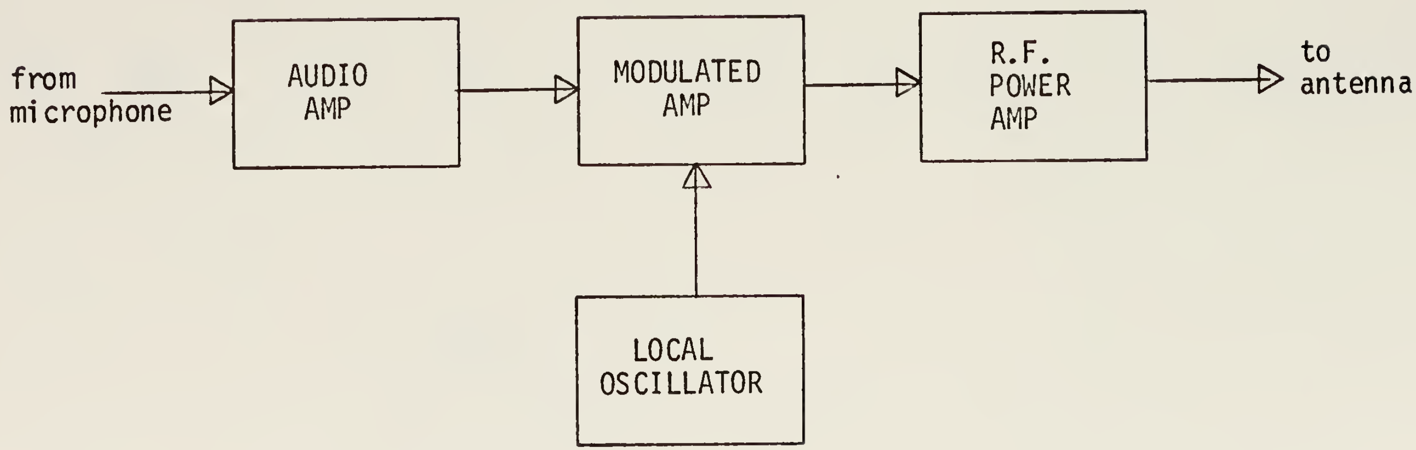


FIGURE 1. Typical AM Transmitter

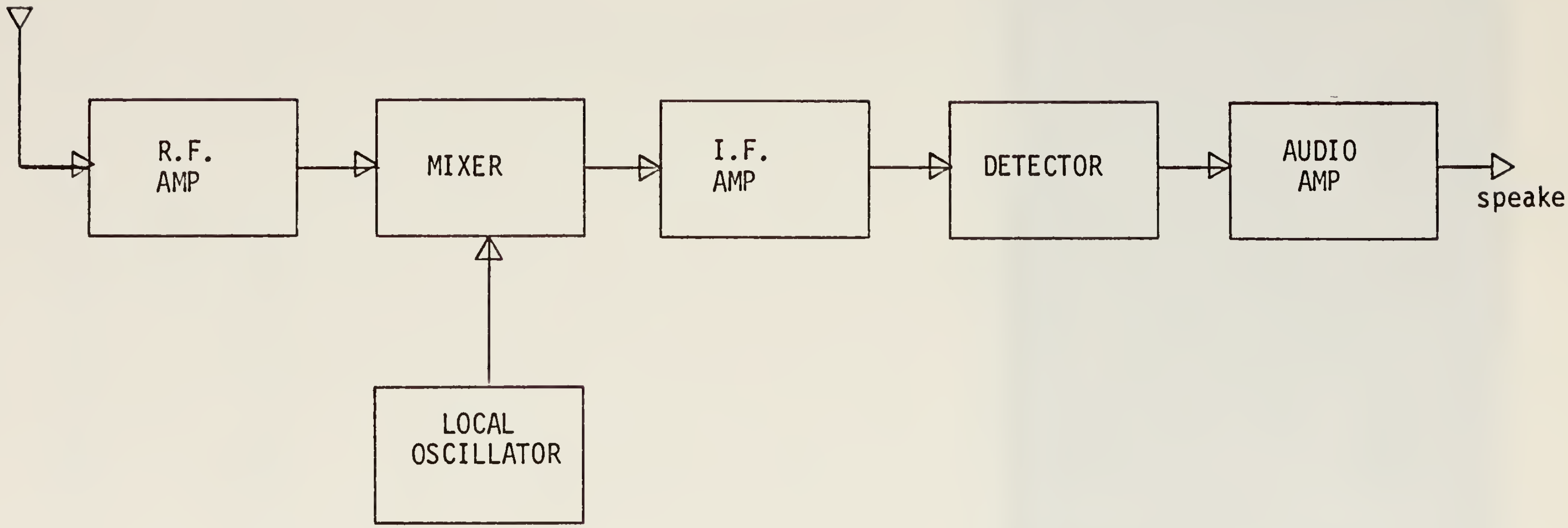
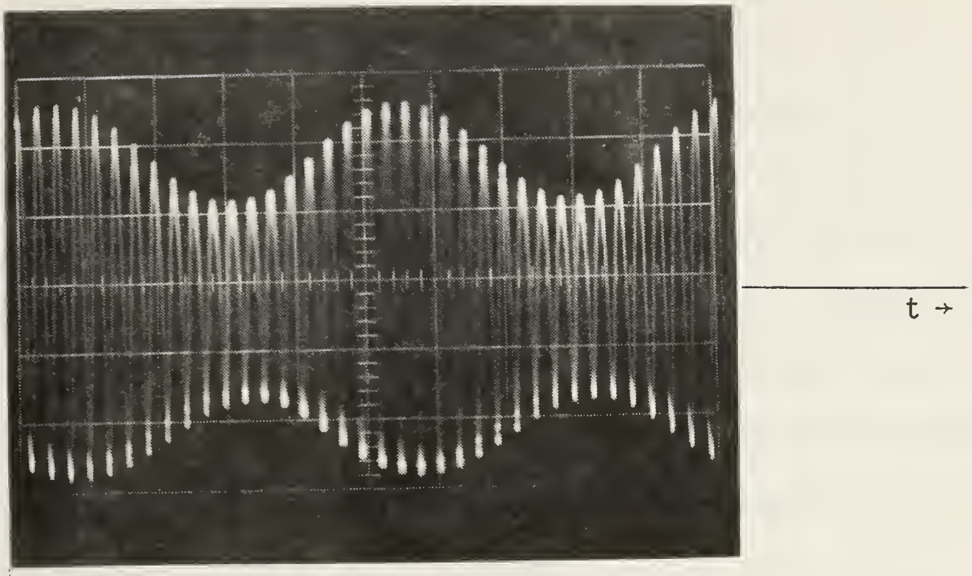
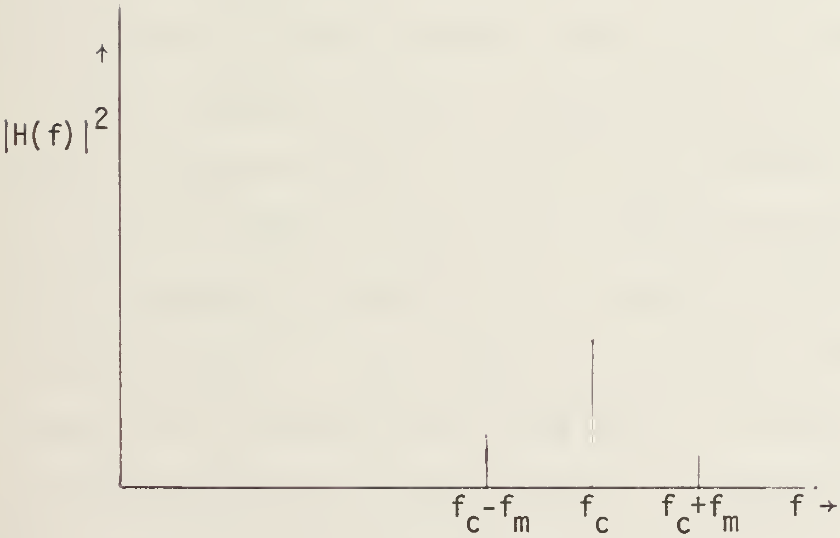


FIGURE 2. Typical Superheterodyne AM Receiver



(a)



(b)

FIGURE 3. (a) Time Domain Waveform. (b) Power Spectrum.

III. SINGLE SIDEBAND - GENERAL

Single sideband is a form of amplitude modulation in which only one of the information sidebands is transmitted. This is possible because the two sidebands are mirror images of each other and carry the same information. Depending upon the single sideband mode used, a full or reduced carrier, or no carrier at all may be transmitted. As was stated earlier, single sideband was used mainly for wire transmissions until the technique was applied to radio.

Single sideband is usually produced in one of two ways. There is a third method developed by Weaver,[4] which is essentially a combination of the other two methods. Although this method appears to achieve deeper sideband suppression, it offers no simplification and is not in general use.

The simplest and most straightforward way to produce a single sideband signal is the filter method. In this method, the audio signal is fed into a balanced modulator. The output of the balanced modulator is a double sideband suppressed carrier signal. This signal is then fed into a filter, which passes one sideband and suppresses the other. The amount of unwanted sideband suppression is a function of the filter. This method has the advantage of simplicity, but requires a steep-skirted filter if low frequency information signals are to be included. Figure 4 shows a block diagram of the filter method of single sideband.

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[4]Weaver, D.K., "A Third Method of Generation and Detection of Single Sideband Signals," Proceedings of the I.R.E., Vol. 44, December 1956.

The second method is the phase difference method. Two balanced modulators are used, and the idea is to shift the phase of one or both of the signals so that when the two signals are added together, one sideband is reinforced and the other sideband is cancelled. Figure 5 is a block diagram of this method. The audio signal and local oscillator signal fed directly to modulator 1. The inputs to modulator 2 are shifted 90°. In other words, the audio signal is shifted 90° with respect to the audio input to modulator 1. Similarly, the carrier signal is shifted 90° with respect to the carried input to modulator 1. The outputs of the modulators are summed. If the phase relationships can be maintained, the result is that one sideband is reinforced, while the other is suppressed. In practice, it is difficult to design a phase shifting network which will perform properly over the entire band of the audio signal. However, if separate phase shift networks are used in each branch of the circuit, the proper phase relationships can be maintained over the desired frequency range. Unwanted sideband suppression is a function of how accurately the phase relationships can be maintained and the relative amplitudes of the signals to be added. This method of single sideband production is somewhat more complex, but it requires no sharp discrimination in frequency. It can, therefore, pass signals which are much lower in frequency.

In practice, with either method, the sideband production and suppression may take place at some intermediate frequency.

Then the signal is translated to radio frequency. From that point on, linear amplifiers must be used.

A single sideband receiver looks similar to an AM receiver, except that product detection is used. The incoming radio frequency signal is amplified and translated to an intermediate frequency. This signal is amplified and passed to the detector. The detector is another mixer which translates the signal to the audio band. This signal is amplified and passed to the speaker. Figure 6 is a block diagram of a single sideband receiver. The band-pass filter just before the detector is only wide enough to pass the information signal. Its purpose is to eliminate noise outside of the signal bandwidth.

Mathematically, a time domain representation of single sideband signals is not simple, except in the trivial case of sinusoidal modulation. Therefore, in the following sections, the frequency domain will be emphasized.

There are three modes of single sideband in common use today. They are the A3H, A3A, and A3J modes. The following sections will define and discuss each of these modes.

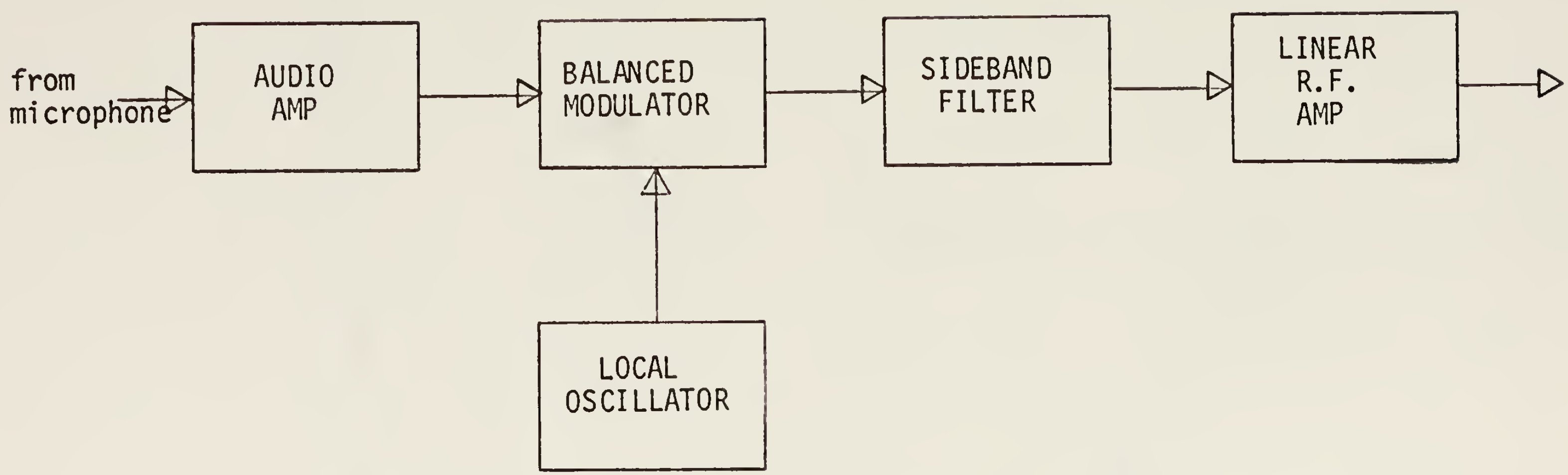

FIGURE 4. Filter Method of Single Sideband Generation

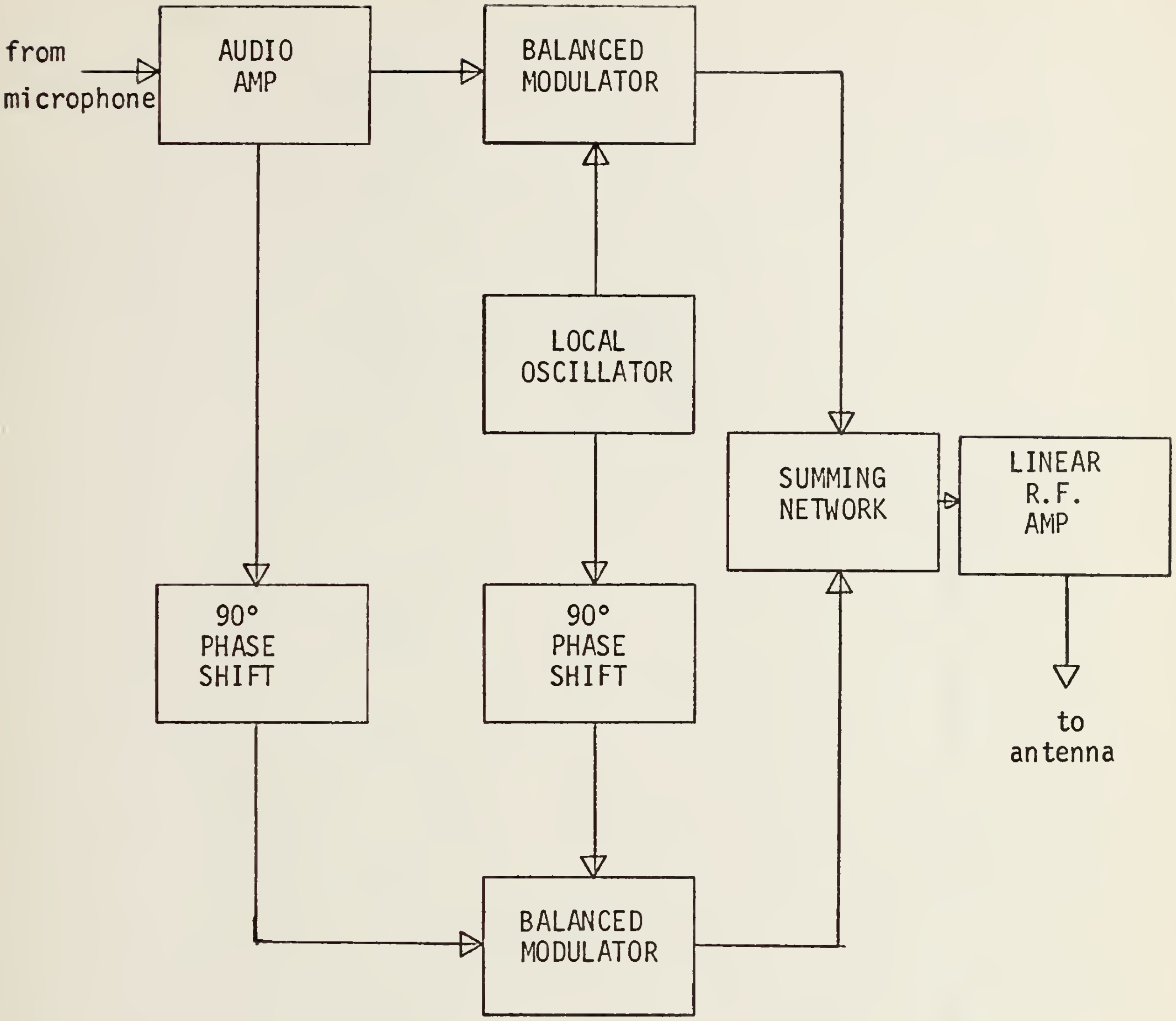

FIGURE 5. Phase Difference Method of Single Sideband Generation

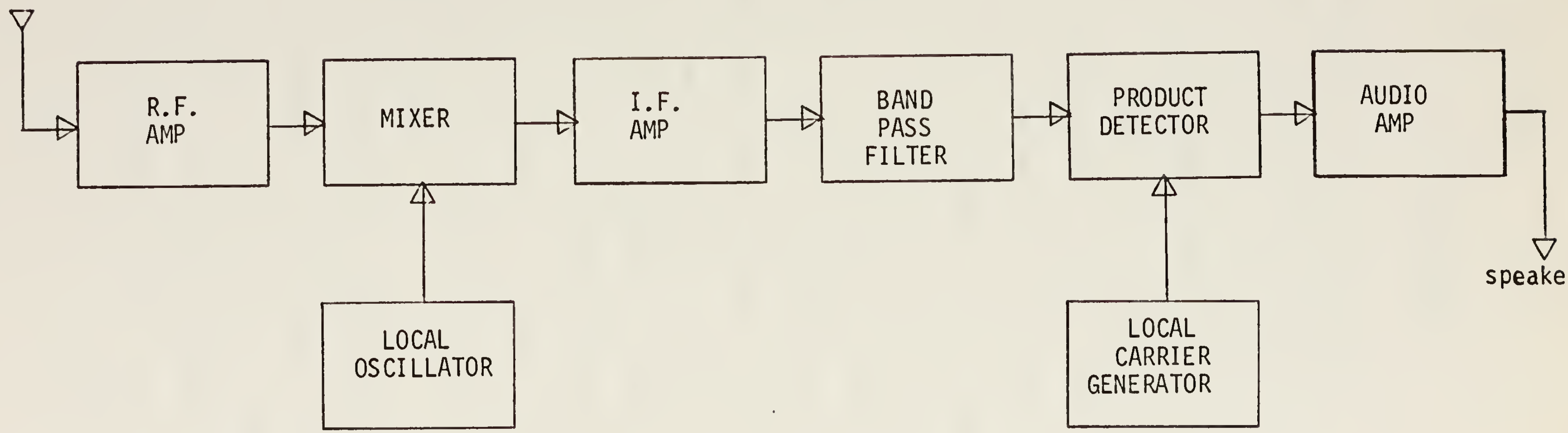

FIGURE 6. Typical Single Sideband Receiver

IV. A3H MODE

A3H is defined by the International Radio Consultative Committee (CCIR) as a single sideband emission in which the carrier is 6 dB below the peak envelope power (PEP). It is also called single sideband-full carrier, because the carrier power is equal to that of a standard AM signal.

In most transmitters, an A3H signal is produced by first producing a single sideband-suppressed carrier signal. Then the carrier signal is added. In the case of A3H, the carrier amplitude equals the sideband amplitude. Figure 7 shows the power spectrum of a sinusoidally modulated A3H signal.

An A3H signal can be demodulated in two ways. In a single sideband receiver, product detection is used. However, it can also be demodulated in a standard AM receiver, using envelope detection. A little care must be taken, though. At 100% modulation, up to 24% distortion results from envelope detection of an A3H signal. Reducing the percentage of modulation reduces the distortion, but has the effect of reducing signal power.

With product detection, the sideband frequencies are translated to baseband without modification. There is, therefore, no signal-to-noise ratio improvement in the detector. However, since the bandwidth of a single sideband receiver in only one-half as wide as a standard AM receiver, only one-half the noise power is admitted. Thus, for an

A3H signal, whose sideband power equals that of a standard AM signal

$$(S/N)_{A3H} = (S/N)_{AM}$$

The coherent addition of sidebands in the case of standard AM is offset by the reduction of noise power.

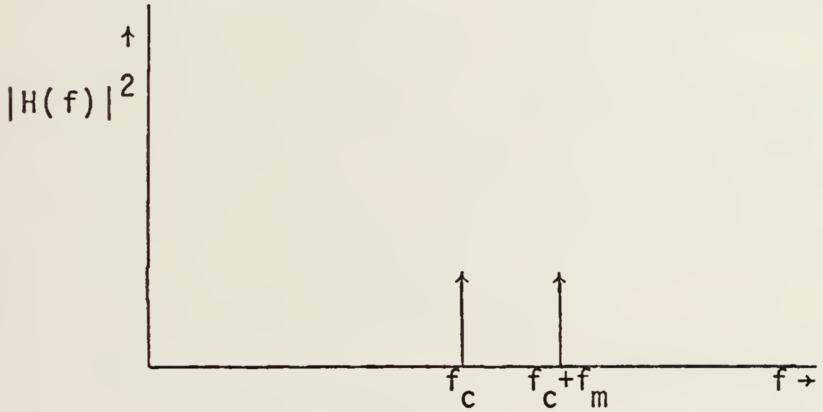

FIGURE 7. Spectrum of a Sinusoidally Modulated A3H Signal (Upper Sideband)

V. A3A MODE

A3A signals are defined by the CCIR as a single sideband emission in which the carrier power is 16 dB below PEP. This mode is also called single sideband reduced carrier, since the carrier power is 10 dB lower than in the full carrier mode.

An A3A signal is normally produced by first creating a single sideband suppressed carrier signal. Then, as with A3H, carrier energy is added. However, in the case of A3A, much less carrier is added. Figure 8 is the power spectrum of a sinusoidally modulated A3A signal.

The A3A mode can only be demodulated by a product demodulator. There is insufficient carrier amplitude to permit the use of an envelope detector. To attempt to do so results in an untelligible signal.

As with A3H, there is no improvement in signal-to-noise ratio in detection. Therefore, for equal sideband power,

$$(S/N)_{A3A} = (S/N)_{A3H}$$

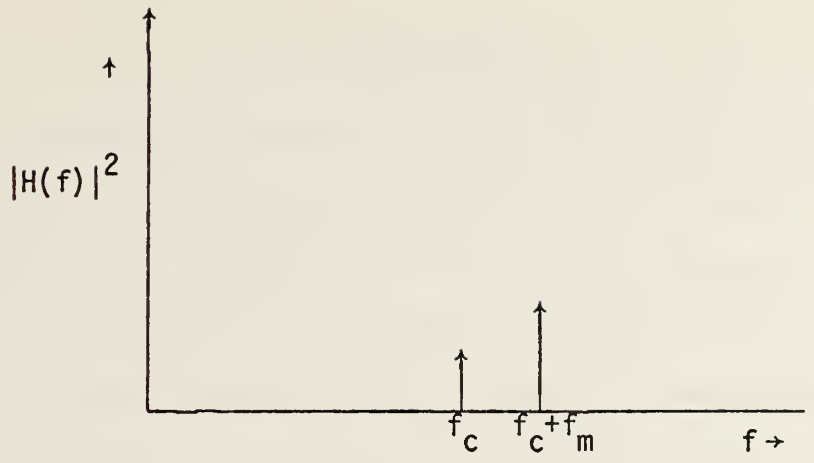

FIGURE 8. Sinusoidally Modulated A3A Spectrum (USB)

VI. A3J MODE

A3J signals are defined by the CCIR to be single sideband emissions in which the carrier power is at least 40 dB below PEP. It is also called single sideband suppressed carrier.

A3J is the signal from which the other modes are derived. It is normally produced by the filter or phase difference methods discussed earlier. There is no carrier power added. Figure 9 shows this power spectrum.

A3J must also be demodulated with a product detector. The signal is translated to the audio range. And as with the previous modes, there is no improvement in signal-to-noise ratio, leaving us

$$(S/N)_{A3J} = (S/N)_{A3A} = (S/N)_{A3H}$$

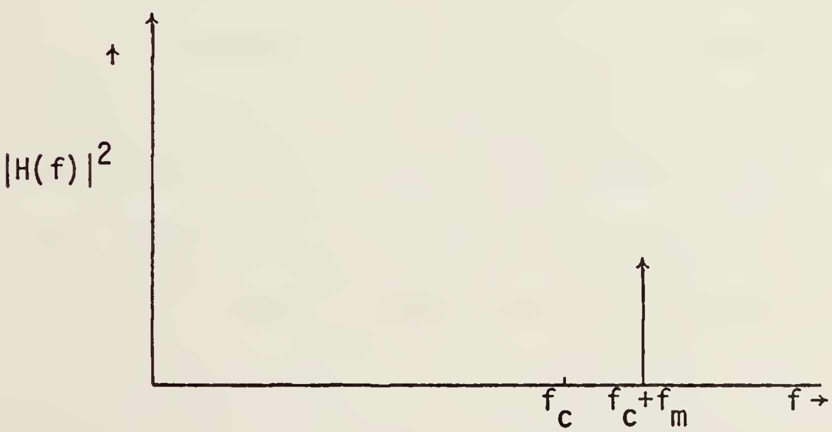

FIGURE 9. Sinusoidally Modulated A3J Spectrum (USB)

VII. SSB-AM COMPARISON

Under ideal propagating conditions, with high carrier-to-noise ratios (for AM), no detector threshold effects, and equal sideband powers; standard AM and single sideband can provide identical performance.[5] However, ideal conditions regularly exist only in laboratories, and are of little interest in a working situation.

From a transmitting point of view, single sideband is much more efficient than standard AM. Depending upon the mode, single sideband transmitters produce reduced or suppressed carrier signals; thus reducing the so-called wasted power. And when no carrier is sent, all power is "talk" power. The carrier power in AM is not in reality wasted, since its presence is required for envelope detection.

This efficiency of power helps in two ways. First, in small pleasure craft, sources of energy may be limited. Thus any ways to reduce power consumption are an advantage. Secondly, the demands placed on the equipment are reduced. For example, a 50 watt AM transmitter and associated hardware must be capable of 200 watts peak power. Tests have shown that under practical conditions, equal performance can be obtained when single sideband power is equal to one sideband

[5]Fundamentals of Single Sideband, Collins Radio Company, Cedar Rapids, Iowa (1959).

of AM.[6] Thus a single sideband transmitter with a power output of 12.5 watts PEP can perform as well as an AM transmitter with carrier output of 50 watts RF power.[7]

A second advantage of single sideband is the reduction in spectrum and interference. This results from the elimination of one sideband and (again, depending upon the mode) reduction or suppression of carrier power. However, this requires close attention by operating and maintenance personnel. The Radio Regulations of the International Telecommunications Union allow, for ship stations in the 1.6-4.0 MHz band, a frequency tolerance of 200 Hz per MHz. This is the maximum permissible departure from the center frequency. At 2182 kHz, then, a deviation of approximately 400 Hz is permissible. This means that in the extreme case, there could be 800 Hz overlap between upper and lower sideband users. This may or may not be significant in a given situation. Also entering the spectrum clutter argument is the fact that the A3H mode does indeed transmit a full carrier signal.

There is another factor which affects the interference question. In some lower priced (c. $700) transceivers, only the upper sideband is available. If only one sideband is

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[6] Honey, J.F. and Weaver, D.K., "An Introduction to Single Sideband Communication," Proceedings of the I.R.E., vol. 44, December 1956.

[7] Fisk, B. and Spencer, C.L., "Synthesizer Stabilized Single Sideband Systems," Proceedings of the I.R.E., vol. 44, December 1956.

available for use, then the spectrum of the other sideband is not being effectively utilized. Strictly speaking, this has nothing to do with the merits or demerits of single sideband, since all manufacturers could easily offer both sidebands. However it is an existing condition and deserves mention.

Perhaps the greatest advantage single sideband has over standard AM is its relative insensitivity to selective fading effects. Selective fading is caused by multi-path effects, the result of reflections off the ionosphere.

Selective fading is a function of frequency.[8] This means that the carrier and sidebands are not affected as a single unit, but as separate entities. As a result, as the carrier passes through a minima, the sidebands may be unaffected. This has the effect of causing distortion as though the signal were overmodulated. Selective fading can also cause phase shifts between carrier and sidebands. This leads to a received waveform which bears little resemblance to the transmitted waveform.

At 2182 kHz, the ionosphere is a pretty good mirror. This is fine for long distance sky-wave propagation, but 2182 kHz was selected for primary propagation to be by surface wave. Selective fading effects introduced by interference between sky wave and surface wave become most apparent in the late afternoon and early evening hours; which is also when distress calls arise. Consequently, any means of reducing selective fading effects is an advantage.

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[8]Brown, R., Martin, D.K., and Potter, R.K., "Some Studies in Radio Broadcast Transmission," Procedings of the I.R.E., vol. 14, February 1926.

Because single sideband uses product detection, there is no necessary phase or amplitude relationship between carrier and sideband. Selective fading can affect the received signal strength, but this generally does not affect intelligibility.

Single sideband does possess some distinct disadvantages, which are closely related. The first of these is that of reception. With the exception of A3H, all modes require product detection. This means that a signal must be reinserted at the carrier frequency or very close to it. In the absence of noise, up to 50 Hz error can be tolerated without serious loss in intelligibility. However, in situations of low signal-to-noise ratio, 10-50 Hz error can have a more serious effect.[9] Very stable frequency synthesizers are available in some transceivers, but at considerable cost. This problem is aided somewhat by the transmission of some carrier power, as is the case with A3A.

A second disadvantage of single sideband is the cost and complexity of the equipment. An AM transceiver can be built very simply and cheaply. Less stable oscillators can be used, and simple diode detectors. On the other hand, stable oscillators, and phase shifters or sharp filters add considerably to the cost and complexity of a single sideband transceiver.

A third disadvantage of single sideband is that it is not compatible with AM. Except for the A3H mode, a standard AM receiver can not demodulate a single sideband signal. A

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[9] Honey, J.F. and Weaver, D.K., op. cit.

single sideband receiver can demodulate an AM signal, but if the local carrier generator is not precisely on frequency, a carrier beat frequency will be heard. This is only a disadvantage if the two schemes are to co-exist. If everyone is required to use single sideband, the compatibility problem, obviously, does not exist.

The preceding was a comparison of single sideband versus standard AM. The next step is a comparison of the various single sideband modes.

In general, it can be stated that the more carrier energy added, the more the signal acquires the characteristics of standard AM. And along with the characteristics come the advantages and disadvantages of standard AM.

The A3H mode most closely resembles standard AM. There is a considerable amount of power in the carrier. This reduces the available signal power for a given peak power, and adds to spectrum clutter. It can be demodulated by an AM receiver, but using envelope detection opens the door to the selective fading problem. However, the stability problem in a single sideband receiver is greatly reduced by transmitting all that carrier energy.

The A3A mode possesses fewer characteristics of standard AM, and more of pure single sideband. The reduced carrier energy adds little to spectrum clutter and increases the available signal power. This mode can not be demodulated by an AM receiver, but the carrier power does aid in the stability of a single sideband receiver.

The A3J mode is pure single sideband. For all practical purposes, there is no carrier power transmitted. All power is information power. It is less subject to selective fading effects, but receiver stability can be a problem.

VIII. THE A3H PROBLEM

In the past two or three years, many owners of single sideband equipment in the Puget Sound and Alaskan regions have reported drastic reductions in the range of transmission with the A3H mode. Reports have also been received from dealers and technicians to this effect.

The International Marine Consultative Organization has predicted that equivalent transmission ranges can be achieved, for standard AM and A3H, with a 15 watt RF carrier (for AM) and 60 watt PEP (for A3H). At 100% modulation, both signals have a 60 watt PEP. However, the FCC authorizes 600 watts PEP, for a 100% modulated AM signal; while only 150 watts PEP is authorized for A3H. In a letter to U.S. Coast Guard Headquarters, Mr. F.B. Mossman of the North Pacific Marine Radio Council reported the results of some tests he conducted. He used a 15 watt carrier AM transmitter and a 100 watt PEP A3H transmitter. Reception was by an AM receiver. Random number and letter groups were transmitted and the number of errors was recorded. The error percentages were within 1% of each other. It was reported that the A3H signals were louder, but the AM signals were clearer. That result is to be expected. The A3H signal was transmitted at a greater power. However, in an AM receiver, as was mentioned earlier, an A3H signal undergoes distortion, because of envelope detection.

In another test, conducted by the U.S. Coast Guard, precision attenuators were used to simulate real conditions. Maximum authorized power levels were used for AM and A3H transmissions. Reception was again with an AM receiver. Attenuation was added to a standard level signal to provide a 10 dB SINAD at the audio output, to determine a relative received signal level. Using AM as a reference, the A3H signal was -8 dB. This suggests a range of only 40% that of AM. Part of this loss again may be due to the distortion in an AM receiver and greater bandwidth, but the major reason is the lower power that is authorized.

A3H appears to be a very poor mode of transmission. It looks like a modified AM transmission in a single sideband world. It lacks only one sideband from being a standard AM signal, but it is subject to single sideband power level limits. It is susceptible to selective fading on AM receivers, and has a lot of wasted carrier power on SSB receivers. It lies somewhere in the middle, between the two worlds of conventional AM and single sideband.

There are three possible solutions. The first would be a return to standard AM. This, however, would be a step backward, and is not a good solution.

The second solution would be an increased authorized power on A3H. This would increase the range of an A3H signal. But this also defeats the underlying goal of using minimum power to achieve maximum benefit.

The best solution is an immediate conversion to A3A or A3J modes, consistent with the rest of the 2 MHz band. With the elimination of carrier power and reduced bandwidth of a single sideband receiver, the full benefit of single sideband can be realized. The effect of this conversion is discussed in the next section.

IX. THE EFFECT OF A SWITCH TO SSB

2182 kHz is an international distress and calling frequency. It is intended for ranges between 30 and 300 nautical miles. It is monitored by all U.S. Coast Guard stations along the coast and by ships at sea. Until the recent establishment of a VHF-FM coastal communications network, it was also the primary distress frequency for all types of pleasure craft. This is what led to the overcrowded condition on this frequency. The equipment was relatively inexpensive, and available to all boaters. Many boaters would call other craft on 2182 kHz and fail to switch to another frequency, once contact was made.

A switch to single sideband, coupled with another regulation, will do much to reduce the congestion on 2182 kHz. This is a result of the economics, as well as single sideband itself. The other regulation mentioned earlier is in regard to the VHF-FM network. This is intended to be the primary means of communication up to approximately 30 miles off the Coast. Before a mariner can be licensed on 2182 kHz, he must first obtain a VHF-FM license. This equipment represents an investment of $300-$400 for a transceiver. This does not include an antenna and associated hardware. Once that obstacle is passed, the mariner faces an investment of about $700 for a less expensive SSB set and up to $1000 or more for a more powerful transceiver. It appears that only those

who really need the single sideband will invest the sums of money necessary to operate on 2182 kHz. But anyone operating outside of coastal waters, such as large yachts, fishing boats, and merchant ships; will have this need. What has been accomplished is to eliminate the smaller boat from this frequency band.

There has already been a considerable impact in this area. Many boaters and fishermen are unwilling or unable to make the investment of money and are turning to the lower cost Citizens Band equipment. Some companies have dropped out of the HF band market, and increased their CB line.

The apparent result is that the problem has been shifted from 2182 kHz to the already overcrowded CB area. At present, the Coast Guard does not monitor CB. This may in the future present a new problem to come under consideration.

It is apparent that recreational boating is continuing to grow rapidly, and that these recreational boaters and small commercial fishermen will present an ever increasing communications need for the conduct of normal Coast Guard missions of search, rescue and law enforcement. This major problem still must be addressed; it will not be resolved at this time by the switch to SSB modes.

X. SUMMARY

The need for effective maritime communications is great. This is especially true on a distress frequency such as 2182 kHz. The equipment requirements for such communications are first, that the equipment fits within the power capabilities of the potential user; and secondly, that it be within the financial means of the potential user. This second requirement includes both the initial investment, and the maintenance of the equipment.

Standard AM consists of a carrier and two sidebands. At full modulation, which in practice is not often reached, the power in the carrier is twice that of the sum of the sidebands. But, the sidebands contain the information. So, to obtain reasonable signal power levels, the total power capabilities and requirements must be significantly raised. The sole purpose of retaining the high power carrier is to satisfy the second requirement. A high power carrier means envelope detection. And envelope detection means simplicity and lower cost.

On the other hand, single sideband is just what the name says; one sideband. Depending upon the mode, no carrier or a reduced carrier is transmitted. The power requirements are much lower. But, the trade-off is cost and complexity, at both ends of the transmission link. Production and reception of single sideband is more involved and more expensive.

With regard to 2182 kHz, A3H is a poor choice. To realize the full potential of single sideband, a switch to A3A or A3J is recommended.

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A comparison of AM and various SSB models on 2182 kHz.